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PROJECT NO. 520-001-07X

CHARACTERISTICS OF AIRCRAFT FIRE DETECTION SYSTEMS

by

Julius J. Gassmann

National Aviation Facilities Experimental Center
Test and Evaluation Division
Aircraft Branch
Propulsion Section
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DEPARTMENT OF TRANSPORTATION
FEDERAL AVIATION ADMINISTRATION
NATIONAL AVIATION FACILITIES EXPERIMENTAL CENTER
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INTRODUCTION

Purpose

The purpose of this project was to study the characteristics and evaluate the performance of the fire detection systems used on present day jet aircraft or proposed for use in the immediate future and to provide information with respect to tendencies to produce false fire warnings.

Background

Since the beginning of the turbojet era, up to the year 1966, powerplant fire detection systems provided four false alarms to every true alarm. Of these true alarms only a very small portion were fire alarms, some being of concern and others being as much a nuisance as the false warnings.

This large number of false warnings resulted in considerable monitary losses to airline operation; an unnecessary strain on the crew and, of greatest importance, a hazard to the safety of the passengers because of needless unscheduled landings. In designing the powerplant fire detection systems for the jet aircraft during their introduction into airline service these systems were often overdesigned, the purpose being to safeguard against the aforementioned situations.

Because of the large number of false fire warnings, the overall ratio being 81% of false to 19% true, and in some fleets one false warning every 2,500 hours of aircraft operation, a program was initiated to study and improve the dependability of the fire detection systems. This program was active during the years 1964 through 1968.

During most of this time the large number of false fire warnings continued. During the latter part of 1966 and the early part of 1967, the fire detection systems in some sizable fleets of aircraft were redesigned and installed more conservatively in the powerplants. As a result, the ratio of false fire warning to true fire warnings decreased to an acceptable level and the effort under this project was terminated.

Since the state-of-the-art has brought about the marked reduction in false fire warnings, this report will be concerned primarily with the precise operating characteristics as well as the strong points and the weak points of the powerplant fire detection systems used on the present day jet liners or proposed for use in the very near future.

DISCUSSION

General Procedure

Various configurations of detection systems were subjected to elevated temperature in an electric furnace to determine the characteristics of the set point. After determining the set point of a configuration, a contaminant was introduced into the connector involved and a similar test was conducted to determine whether the contaminant had an adverse effect on the system operation. The contaminants used were (1) demineralized water, (2) tap water, (3) 5% salt solution, (4) 20% salt solution.

The effect of a short to ground was also determined. This simulated the grounding of a chafed lead wire or the open end of a broken sensing element.

The sensing elements of each system were also exposed to a standard 2000°F six-inch diameter test burner flame and a determination was made of the response and clearing times. Total exposure to the flame for determining the clearing time was 60 seconds. Whenever applicable, the same sensing element in an armored configuration was subjected in a like manner to the standard burner flame for determining the effect of the armor on the response and clearing times of the sensing element.

Several surveillance type fire detection systems were subjected to the standard five-inch gasoline pan fire, as required in TSO-C79. The effect on the system sensitivity was determined by subjecting one and four sensors to the standard flame. Determinations were also made of the effect on sensitivity of background radiation, colored lamps, and direct sunlight.

Specific Systems

The same test procedure could not be used on every system and the results are not necessarily directly comparable because of the marked differences in the principle of operation and other characteristics of the systems. Many systems are quite similar in operation but others are not. For this reason the detailed system description, the principle of operation, the specific test procedure, and the results and discussion are grouped together under the heading of each specific system, or group of systems where applicable.

Graviner Firewire Triple FD System:

System Description - The basic components of a Firewire system are the sensing elements or loop and the control unit. A complete system incorporates a lamp, manually operated test switch and associated wiring, connectors and mounting hardward.

Each element consists of a stainless steel capillary containing a temperature-sensitive filling material and a coaxially located wire electrode, and is terminated at each end by an end fitting which incorporates a coupling nut.

The control unit is a small electronic module enclosed in a steel container which houses a transformer, rectifiers, and other electronic components. The unit operates from a 400-cycle input to the transformer or from a direct current power supply through a transistorized oscillator to the primary of the transformer.

Principle of Operation - The secondary of the transformer in the control unit supplies power for the internal charging, read-out and alarm circuits. The charging circuit feeds half-wave rectified power to the sensing elements which store the energy received when the temperature rises above a predetermined level as a result of an overheat or fire. During the reverse half of the power cycle no power is fed to the elements and if, due to the high temperature, current from the previous half cycle has been stored it will discharge into the read-out circuit. When the discharge reaches the critical level the read-out circuit activates the alarm circuit which in turn operates the aircraft warning system.

A short circuit in the sensing element loop or its associated wiring will result in the read-out circuit receiving a signal which is always below the warning level. Thus a false fire warning cannot occur.

The system test circuit is so arranged that operation of the aircraft test switch will automatically prove, (a) the continuity of the sensing element loop and its wiring, (b) that the insulation resistance of the element loop is at an acceptable level, and (c) that the control unit is operative.

Results and Discussion - Two basic systems were evaluated. One system was similar to that used on American Air Lines BAC-111 power plants and consisted of control unit type 364D and two elements type D 2370/120. The other system was similar to the ones used on the super DC-8 series 60 aircraft. This system consisted of the same type 364D control unit and one each of Armored elements P/N D5030 and P/N D5025. These two elements have characteristics identical to the D2370 elements except for the temperature set point and are physically different in that they are armored.

A test series was conducted to determine the effect of various values of resistance shunting the center conductor to ground. A system configuration was used that was similar to the BAC-111 configuration with a set point of 785°F. Results were as shown in Table I.

TABLE I

THE EFFECT OF SHUNTING RESISTANCE ON THE OPERATION OF THE GRAVINER FIREWIRE TRIPLE FD SYSTEM

Shunting Resistance (Ohms)	Alarm Point (Degrees F)	Remarks
None Imposed	785	Test O.K.
7500	800	Test O.K.
1500	950	Test O.K.*
1280	1115	Fail to Test
430	1420	Fail to Test

* Light remained on after test. System reset by interrupting 400-cycle supply before proceding with test.

This demonstrated that an indication of the system being unserviceable appeared well before its fire detection ability was lost. It is also evidence that the system will become inoperative due to a malfunction rather than produce a false alarm.

This was demonstrated further by a series of tests in which contaminents were introduced into a connector and then subjected to elevated temperatures in an electric furnace to determine the effect on the set point. The configuration used had a set point of 930°F. The contaminents used were: (1) demineralized water, (2) tap water, (3) 5-percent salt water solution, and (4) 20-percent salt water solution.

The use of demineralized water had no significant effect on the system operation.

The use of tap water and a 5-percent solution as contaminents had no significant effect on the set point, but did cause the system to "fail to test" (no response when system test was effected).

The use of 20-percent solution as a contaminent raised the set point about 100°F (generally considered tolerable in that temperature range), and also caused the system to "fail to test."

The effect of the armor on the sensing elements is indicated on Table II. This table gives the response time when the sensor was exposed to the standard 6-inch diameter, 2000°F test flame and the clearing time after being removed from a one minute exposure to the test flame.

TABLE II

THE EFFECT OF ARMOR ON THE SENSITIVITY OF GRAVINER FIREWIRE

Element	Response (Seconds)	Clearing (Seconds)	Remarks
Firewire D2370	3	32	785°F set point
Armored D5030	3	120	475°F set point
Armored D5025	7	66	800°F set point

These results indicate that the addition of armor could approximately double the response as well as the clearing times for elements of similar set points.

Edison Fire and Overheat Detection System:

System Description - The Edison fire and overheat detection system is used in the powerplants on all the DC-8 series 10 through 50 aircraft. This system consists of a control unit and six sensing elements connected in series along with associated circuitry and indicators.

The temperature-sensitive element of the system consists of a special coaxial cable equipped with hermetically sealed high-temperature connector plugs at both ends. A single solid conductor of an alloy suitable for the temperature involved, forms the cable core. A seamless tube of similar corrosion resistant metal serves as the sheath. The space between center conductor and sheath contains a highly compacted material whose resistance decreases with increased temperature.

The control unit P/N 377-115-22 employs two separate alarm channels, one for "fire" and the other for "ground fault." These two channels are interconnected and time phased in order to discriminate against false fire warnings as a result of any normally ungrounded conductor accidentally making a continuous or intermittent contact with the sensor cable sheath or any other grounded portion of the aircraft. The early DC-8 aircraft were equipped with a control unit of a less sophisticated design and a false warning resulted when a normally ungrounded conductor came in contact with the aircraft ground. These control units were replaced with the discriminator type control unit whenever service was required and at present there are few if any of the older models in service.

Principle of Operation - The control unit consists of two Wheatstone bridge circuits, two silicon solid state null sensors operating into the Fire and Ground Fault warning relays and suitable silicon diode protection networks. These components along with the power transformer, fire memory relay, master warning relay and reset relay are housed in a non-hermetically sealed case. All connections are brought out of the control through a miniature quick-disconnect connector.

Where 400-cycle current is used, the input power is transformed and rectified to a 28-volt d-c level which is transient suppressed and filtered by a resistor, a zener diode, and a capacitor.

In normal operation the sensor cable resistance decreases as its temperature rises, thus as the sensor cable is heated and its resistance falls below the fire alarm point the fire relay actuates, disabling the ground fault relay by disconnecting its ground return and simultaneously transferring power from the reset coil of the fire memory relay to the latch coil. The fire memory relay actuates, energizing a master warning relay which in turn causes the Firex handle and Master Warning "Fire" lamps to illuminate as well as sound an audible alarm. The Master Warning lamps can be extinguished and the audible alarm silenced by operating the reset switch which causes the reset relay to lock itself in and disable associated alarm circuitry. If the sensor cable temperature is reduced its resistance will increase above the fire alarm point causing the fire relay to drop out and causing the memory relay to reset. This in turn deenergizes the master warning relay and causes the warning lamps, audible alarm and reset relay to return to the normal standby condition. However, should the cable resistance continue to fall and pass the ground fault alarm point the ground fault relay being deactivated will not be energized.

If a short circuit to ground occurs from a fire detection sensor cable center conductor and the apparent cable resistance falls through the fire and ground-fault alarm points essentially at the same time, the ground-fault alarm relay will actuate before the fire relay, lighting the "Ground-Fault" light and at the same time disabling the fire relay and "Fire" alarms by opening the fire relay ground return. The fire relay circuit is deliberately delayed to provide this lockout feature for continuous or intermittent short circuits. The induced delay is short with respect to the thermal response of the cable and therefore does not interfere with normal operation.

The function of the fire memory relay is to provide fire alarm memory in the event that the input power is disrupted because of emergency conditions that exist during an aircraft fire. The basic control discriminates between a true fire and a short circuit by having the control recognize the manner in which the sensor cable resistance falls. An instantaneous change in cable sensor resistance to a value below the ground fault alarm resistance is rejected as a fire but is accepted as a ground fault. Therefore, should a fire occur, and the cable sensor resistance eventually drops below the ground fault alarm resistance, a disruption of power will drop out the fire relay. Subsequent reapplication of power will result in an instantaneous sensor signal which will be rejected as a fire and accepted as a ground fault. However, the fire memory relay will have latched in on the initial fire alarm and would not have changed state, as does the fire relay, with the loss of power. Upon reapplication of power, the ground fault relay activation opens its contact and prevents the resetting of the fire memory relay which reestablishes the "Fire" warning lights and audible signal. Upon return of the sensor cable to a resistance above that of the fire alarm value the entire circuit will reset and return to normal standby condition. Without the fire memory relay the previous set of conditions would result in the fire alarm being accepted as a ground fault with the subsequent illumination of the "Ground Fault" light and lockout of the "Fire" light.

System integrity is verified through use of an internal test resistor. The test switch when actuated opens the sensor center wire loop and applies the test resistor to the open end of the sensor cable. The sum of the test resistance plus sensor cable center conductor resistance is lower than the fire alarm point and therefore actuates and operationally tests sensor cable continuity, solid state fire sensor, fire relay, fire memory relay, master warning relay, "Fire" warning lights and audible alarm. The ground fault alarm point resistance is lower than the sum of the test resistor and sensor cable resistance. Therefore, the ground fault sensing fire disabling circuit is not actuated or tested when the test switch is actuated. Because of the disabling action of the ground fault relay on the fire relay, a system verification test cannot be accomplished when a ground fault is present.

Results and Discussion - The Edison system evaluated in the laboratory was similar to the ones used in the powerplants of the DC-8 aircraft and consisted of one control unit P/N 377-115-22 and two each of elements P/N 244-036-32, 244-080-32, and 244-210-22. This system incorporates a short discriminating circuit which functioned properly when tested, in that the system did not alarm falsely when the ungrounded conductor was connected to the system ground. The system "fault" light became illuminated as it was designed to do.

The alarm temperature of the system was determined with several contaminents in a connector. Using (a) demineralized water, (b) tap water, and (c) 5-percent salt water solution the alarm temperatures varied between 920 and 930°F. Using a 20% salt water solution as the contaminent, intermittent alarms were noted at temperatures as low as 480°F which is low enough to be considered as a false warning for a system with a nominal set point of 900°F or more.

The response and clearing times were determined for this system when subjected to the 2000°F flame from the standard 6-inch burner. The response time was 8 seconds and the clearing time was 6 seconds. Although not specifically stated in the current TSO, the 8-second response time is not unusual for systems set to operate in the 900°F range when conducted at an ambient of about 75°F.

Fenwal Continuous Fire and Overheat Detection System:

System Description - The basic components of the Fenwal continuous fire and overheat detection system are the control unit and the sensing elements. A complete system incorporates warning devices, associated wiring, connectors, test switch and in most cases, relay units.

The sensing elements consist of a small, lightweight, flexible Inconel tubing with a nickel wire center conductor. The tubing is packed with insulation and a eutectic inorganic salt compound, hermetically sealed and fitted with end connectors.

The control unit, operating directly from the power source, impresses a voltage on the sensing elements. When an overheat condition occurs, the resistance within the sensing element drops sharply, changing the impedance relationship of the control unit network. This impedance change produces an output signal to actuate visible and aural alarms. Systems of this type are used on all of the Convair 880 and many of the B-707 aircraft. This system is also used on the Convair 990 aircraft modified to incorporate dual sensing elements, thereby eliminating the possibility of a false alarm due to any one fault in the element circuits.

Many of the systems in the B-707 have been modified to incorporate shrouded elements (sometimes referred to as armored elements), which are standard elements protected by a full-length perforated outer cover to protect the element from damage in service and during maintenance.

<u>Principle of Operation</u> - The operation of the control unit is based on a magnetic amplifier switching system. The magnetic amplifier consists of six components: a toroidal coil with three windings on it, two diodes and three resistors. Each of these electrically separated windings forms the basis of a circuit, namely; the power circuit, the reset circuit and the control circuit.

The power circuit consists of a resistor and a diode in parallel, with the combination in series with the power winding and the load. The reset circuit consists of a diode, a reset winding, and a resistor, all connected in series. The power and reset circuits are both connected across the power input. The control circuit consists of a resistor and the control winding connected between the center conductor and the outer sheath of the sensing element.

Operation of the magnetic amplifier is based on the magnetic qualities of the toroid core. The core material is easily magnetized and demagnetized. Coils wound about the core have a very high impedance when the core is not saturated and a very low impedance when the core is saturated.

Controlling the impedance of the power winding controls the current flow through the load and the impedance of the power winding is controlled by the sensing element.

In the standby condition the control winding is not effective because the interaction of the power and reset windings prevents substantial current flow in the power circuit. During one-half cycle of the power input, the power winding is energized causing the core to be saturated. The changing flux in the core generates a back emf opposing the flow of current in the power winding. During the second half of the first cycle, the reset winding is energized and because of its phase relationship with the power winding, it demagnetizes the core.

When the sensing element is exposed to an overheat or fire condition, its impedance is lowered, which in turn lowers the impedance of the entire control circuit. The reduced impedance is reflected to the power and reset windings by mutual inductance, thus reducing the impedance of these windings. The magnetic amplifier is designed so that the power winding has many more turns than the reset winding. This is balanced during standby by the resistor in series with the reset winding. When the impedance of the power and reset windings is reduced by the action of the control winding, reduction of the power winding impedance is greater than that of the reset winding. Thus, the amplifier is now out of balance, increased current flows in the power winding, the core starts to saturate increasing the flow of current and maintaining the imbalance. The regenerative action resulting from saturation is responsible for the high power gain of the circuit. The current in the power winding operates the load and is limited in its maximum value by the resistor in the control circuit which also limits the minimum impedance of this circuit. When the temperature is lowered on the sensing element, the alarm indication will cease and the circuit will return to the standby condition, ready to detect another overheat or fire condition.

The operation of the sensing element and its effect on the operation of the control unit are somewhat different than in other continuous detection systems which generally incorporate a thermistor type material. The systems using the thermister type heat sensitive material will, to some extent, average the temperature effect and vary in set point depending on the length of element heated, and to a lesser degree, the ambient of the rest of the sensing element. The Fenwal sensing elements incorporate an inorganic salt as the heat sensitive material. This gives the system a discrete sensing capability which is not dependent upon the length of the heated portion of the element or the ambient of the rest of the sensors. Because of this discrete temperature sensing feature this system is used not only as a fire detector, but as an overheat detector on many aircraft in the leading edges of wings and the fuselage section as a warning of structure overheat.

<u>Results and Discussion</u> - The fenwal system evaluated in the laboratory was similar to the ones used on many of the B-707 aircraft. The system consisted essentially of control unit P/N 35000-15, power relay unit P/N 35801-0 and sensing elements, two of P/N 35543-0-575 and one of P/N 35599-0-900.

This system provided a false fire warning whenever the ungrounded conductor in the sensing element circuit made contact with the system ground.

In determining the effect on system operation of contaminents a configuration was used such that the system alarmed at 590°F. Using demineralized water as the contaminent, no change in the set point was noted. Using tap water, no change was noted on the first and third run but on the second run of the series a warning was received at 440°F.

When salt water, either a 5-percent or a 20-percent solution, was introduced into a connector of the sensing circuit at room temperature, a false warning was received.

The response and clearing times were determined, starting at a room temperature ambient of 72°F, for the elements mentioned above and for shielded (armored) elements P/N 35558-7 and P/N 35558-8. The results are shown in Table III.

TABLE III

THE EFFECT OF ARMOR ON THE SENSITIVITY OF FENWAL ELEMENTS

Element	Response (Seconds)	Clearing (Seconds)	Set Point (Deg. F)
35543-0-575	4	49	580
35599-0-900	6	21	915
Armored	9	85	765
Armored	8	80	780

These results indicate that the armored elements took about 70% longer to respond and over 100% longer to clear than the sensing portion of the assembly would have taken without the armor.

Kidde Continuous Fire Detection System:

System Description - The Walter Kidde and Company has fire detection systems in service on many of the present day jet aircraft. Some of these systems incorporate a variety of optional features. Five of the more commonly used systems are described in this report. Basically all systems consist of a control unit and continuous sensing element. The control unit uses a simple transistorized bridge and trigger circuit to switch on an alarm when the resistance of the sensor drops to a preset level, and automatically resets when the fire or overheat condition has been eliminated and the sensor resistance has risen again. The continuous sensing element consists of an inconel tube sheath that contains a ceramic-like thermistor material in which are embedded two electrical conductors. Suitable end fittings at each end of the sheath provide a hermetic seal and a means of joining sensing elements together with proper electrical continuity.

The optional features include, (1) a short discriminator that discriminates between a lowered resistance caused by a fire and a lowered resistance due to a short circuit, thus preventing short circuits from causing fire warnings. A separate trouble warning indicator, actuated by a short circuit, is available when desired, (2) a two level system which provides an overheat warning at a temperature slightly above maximum normal overheat and second warning at a higher temperature indicating a more severe hazard or fire, (3) an isolated circuit system which takes advantage of the two conductors embedded in the thermistor material. In this system the grounding of one conductor will have no effect whatsoever on the system, (4) the armored element which consists of a sensing element positioned within a prebent protective sheath of perforated stainless steel tubing by closely spaced teflon-asbestos bushings, and (5) the redundant system in which sensing elements are run parallel to each other approximately one-half inch apart. Dual control units within one envelope are usually provided for such a system. These optional features are used individually or in a combination, depending on customer requirements.

Principle of Operation - The control unit monitors the resistance of the sensing element, using a Wheatstone bridge measuring circuit in which the sensing element forms one arm of the bridge, and the trip setting adjustment resistor, another. The bridge null detector is the first stage of a transistor flip-flop circuit. As the element resistance decreases to the null-producing alarm value, the first stage of the flip-flop cuts off, causing the second stage to conduct. The second stage collector current operates a relay whose contacts are used to signal the alarm.

Transient suppression is provided to the control circuit by a zener diode regulator. This will shunt voltage transients as high at 1000 volts without a flicker or fire signal, or damage to the transistor circuits.

The continuous sensing element is a thermistor device whose resistance is an inverse function of the temperature to which it is heated. The heart of this sensing element are the two conductors and the thermistor material that is extruded over them in a plastic state and then fired. This core is threaded into the sheath of inconel tubing and suitable end fittings are ataached to each end. While two conductors are used internally, one is welded to the sheath and the other wire terminates in the single contact of the end fitting. A chemical bond is formed between the two conductors and the thermistor material, while only a mechanical bond is formed between the sheath and the thermistor material. Thus, by grounding one conductor and using the other conductor as the ungrounded conductor a stable and reliable resistance characteristic between them is obtained.

The unique construction of the continuous sensors, in which there are two conductors inbedded in the thermistor material, lends itself readily to an isolated circuit system. This system incorporates sensing elements in which neither conductor is grounded by welding to the sheath. Both conductors are terminated in newly designed coaxial end fitting connectors and connected to a control unit which incorporates an isolation transformer, with suitable coaxial or other wiring. In this manner the sensing element circuit is effectively isolated from the power ground and may become shorted to ground at any one point without affecting the system operation or its performance.

The Kidde short discriminator device is incorporated in a control unit whenever it is required for a detection system not to alarm falsely when the sensing element circuit becomes shorted to ground. Such a control unit employs two resistance monitoring circuits. One, the fire warning circuit, is set to trip at the resistance corresponding to the desired alarm temperature, usually between 200 and 500 ohms. A slight delay is introduced in this monitoring circuit that requires the sensing element resistance to be maintained below the trip setting for a finite period of time, in the order of one or two-tenths of a second. The second resistance monitoring circuit is the short detecting circuit. It is set to trip at a low resistance value, appreciably below the fire trip resistance. There is no delay introduced in this monitoring circuit.

If a short circuit occurs, the system resistance drops practically instantaneously to a low value. While the circuit resistance is now below the fire trip resistance, the fire warning monitoring circuit does not immediately actuate because of the built-in delay. The resistance is also below the trip resistance of the short detecting circuit, and since there is no delay in it, it actuates instantaneously. The short detector circuit nullifies the fire warning if the short detector is actuated first, so that the fire warning signal cannot actuate after the expiration of the delay period.

If a fire occurs, the resistance of the sensing element will decrease relatively slowly and, after reaching the fire trip resistance, will not decrease rapidly enough to reach the short circuit trip resistance before the expiration of the delay period. As a result, the fire warning circuit will be activated. Contacts of the relay in the fire warning circuit are employed to lock out the short monitoring circuit, so that the fire warning will not be interrupted and a short signal actuated, if the fire should be intense enough to heat the element so that its resistance lowers to the short circuit trip value.

Results and Discussion - The systems evaluated under laboratory conditions were:

1. One of the original systems used on some of the Boeing 707 and 720 aircraft. This system consisted of a control unit P/N 890700-0450 and two type 1422-47 and two type 1422-57 elements. This was generally considered one of the early standard systems which would false alarm when the sensing element circuit became shorted to ground.

2. The system used on some of the later 707/720 or as a retrofit on the earlier models. This system consisted of control unit P/N 893229-0450 and two type 1422-47 elements encased in armor. This system has the short discriminator feature.

3. The system used on Braniff Air Lines BAC-111 Aircraft. This system consisted of control unit P/N 892561-0450 and sensing elements P/N 805313, 805314, and 727120. Incorporated in this system were the Kidde Isolated Circuit system and the Kidde Short Discriminator.

4. The system used on the C-141 Aircraft. This system consisted of control unit P/N 892294-0010, four type 1422-37 and two type 1422-57 elements. This system incorporated the Kidde Isolated Circuit, the Kidde Short Discriminator and the two detection level feature.

5. The system used on the DC-9 Aircraft. This was a dual track (redundant) system consisting of two independent control units in one package and two independent and identical sensing element runs in each protected area. The system consisted of control unit P/N 892809-0400 and two each of sensing elements types 1422-25 and 1422-30.

A summary of the results of the tests conducted in the laboratory on the five systems described above are listed in Table IV.

TABLE IV

SUMMARY OF THE TEST RESULTS OF THE FIVE KIDDE SYSTEMS EXAMINED

Aircraft Used On	Response (Seconds)	Clearing (Seconds)	Set Point Deg. F	False Warning When Grounded	Remarks
707-720	7	28	800	Yes	Original installation
707-720	9	35	750	No	Retrofit-armored short discriminator
BAC-111	5	20	825	No	Isolated circuit short discriminator
C-141	6	20	625/760	No	Two level detection Isolated circuit short discriminator
DC-9	3	46	505	No	Redundant system

The table shows two set points for the system on the C-141 aircraft. This is because it is a two temperature level system, the first being the set point for overheat and the second for fire.

The effect on the set point temperature due to contaminents in the sensing element connectors was determined. The first three contaminants used, namely demineralized water, tap water, and a 5-percent salt solution, had either no, or a negligible effect on system operation when introduced into a connector. Using a 20-percent salt solution as the contaminant caused a noticeable reduction in set point in some instances, but was not sufficiently severe to be considered a false fire warning.

Lindberg Fire and Overheat Detector System:

System Description - This is the system used on all Boeing 727 aircraft powerplants. It consists basically of a sensor responder. The sensor element is 0.040 inches in diameter. The outer housing is annealed stainless steel tubing and contains an inert metallic substance which is porous and has excellent heat transfer properties, and a core which is the discrete element. This sensor is sealed at one end and the other end is integrally attached to the responder. The responder, to which the sensor is permanently attached, is essentially a pressure switch and an electrical connector. This electrical connection completes the basic fire detector circuitry. A single pin contact is provided at the other end of the sensor element for test purposes.

The sensor responder unit serves as a general overheat detector and as a fire or severe localized overheat detector; the lower temperature being an average of the temperature conditions along its entire length and the higher or discrete temperature being that of a more localized high temperature. This unit is generally used in conjunction with operating power unit P/N 1011-A or 1014 for operating visual and aural alarms and a means for testing the system.

Principle of Operation - The responder is essentially a high-temperature, pressure operated switch. The switch consists of an insulated stationary contact and a movable contact, which is an integral part of a diaphram. The switch operates with a positive action whenever pressure is increased above a predetermined operating point. The pressure to operate this switch is generated within the sensor element. The core within this element has the inherent property of releasing gas when heated above the preset discrete operating point. The gas returns to the core when the temperature drops below this point, thus reducing the pressure so the switch will again open. The filler material is an inert metallic substance which has excellent heat transfer properties. Its primary function is to conduct heat from the stainless steel tube to the discrete element. It also fills the void spaces, yet is porous enough to permit gases to flow through it. Thus, when a small section of the sensor element is heated to above the "discrete" temperature, gas released at that spot immediately passes through the filler material and spreads throughout the tube, thereby resulting in increased pressure at the switch in the responder and thus produces a warning.

The average response feature of this detector system functions independently of the discrete function. Before the sensor responder is sealed off, the sensor tube is precharged with a second gas. When this gas becomes heated in the confines of the element, the result will be a rise in pressure. An increase in pressure will cause the preloaded diaphragm switch to operate at the desired temperature setting which will cause an alarm due to general overheat. Because there is no interaction between the gases, the overheat and discrete functions will remain independent of each other. By proper processing a wide range of triggering set points can be selected independently of each other.

Results and Discussion - Two basic systems were evaluated. One system was similar to that used on the 727 aircraft. It consisted of sensor responder units as previously described, the sensor portion being routed along the fire walls and around the aircraft propulsion unit. The second system was similar to the ones used as a retrofit system on some 707 aircraft. This system used the basic sensor responder unit but this was combined with a preformed one-half inch diameter supporting tube around which the sensor was wrapped in a spiral manner.

Units from both of these systems were subjected to contaminents in the connector and then to elevated temperatures in the electric furnace. The contaminents used were, (1) demineralized water, (2) tap water, (3) 5-percent salt water solution, and (4) 20-percent salt water solution. The set point of the systems were unaffected by any of these contaminents. The systems could not produce a false warning when the wiring was shorted to ground. In order to produce a false alarm, the two wires leading from the responder must contact each other.

To show the operation of the discrete and general overheat principles of the system, sensors of 6-feet, 10-feet, and 25-feet lengths were subjected to the electric furnace, first with 2-feet of the sensor being heated and then with the total element being heated. These results are shown in Table V.

TABLE V

DISCRETE AND OVERHEAT SET POINTS OF LINDBERG FIRE DETECTORS OF VARIOUS LENGTHS

	Alarm Temperature	
Sensor Responder	2-Foot Immersion (Deg. F.)	Full Immersion (Deg. F.)
1050-800-375-6	680	425
1050-800-325-10	820	375
1050-800-325-25	950	360

Under the heading of "Sensor Responder", the first number is the model number, the second number is the nominal discrete temperature setting of the system, the third number is the average temperature at which the system will alarm and the fourth number is the length of the sensor.

In order to compare the response and reset characteristics of the Lindberg systems as used on the 727 (sensors supported by grommets), and the 707 (sensors wrapped around supporting tube) when subjected to the 2000°F flame of the standard 6-inch diameter burner, results of the tests are summarized in Table VI.

TABLE VI

THE RESPONSE AND CLEARING CHARACTERISTICS OF VARIOUS LINDBERG FIRE DETECTOR CONFIGURATIONS

Sensor Responder	Response (Seconds)	Clearing (Seconds)	Nominal Discrete Set Point (Deg. F.)	Remarks
1050-800-375-6	4	6	800	
1050-800-325-10	5	4	800	
1050-800-325-25	5	2	800	
1786-1100-600-16	4	14	1100	Rigidly supported

From the results in this table it can be seen that the rigidly supported element set at 1100°F responds as rapidly to exposure to the standard flame as does the grommet supported element set at 800°F. However, the clearing time of the rigidly supported element is several times as long but this is of little significance since it is still a very short time compared to those required in the current TSO.

Fenwal Surveillance Fire Detector SFD-500:

System Description - The Fenwal SFD-500 system detects flames by sensing near-infrared radiation. A complete system consists of from one to eight sensors operating through one control unit and a test-indicator unit. Visual and aural alarm indicators may be used or external relays may be employed to actuate almost any type of alarm device.

Principle of Operation - The Fenwal SFD-500 system is an electronic system for detecting near-infrared radiation from flames. The sensor contains a filter to exclude visible radiation. The control unit has a band-pass amplifier to allow only flickering signals, characteristic of flames, to be amplified. A test lamp is provided in the sensor to check the operation of the complete system including the photo-electric cell, the control unit, and the associated wiring.

The system operates from 28 VDC. The sensor's photocell output is coupled to the low impedance input tranformer of the control unit. Signals over a frequency range from 2 to 24 cps are amplified and coupled to a rectifying and integrating network. The d-c signal obtained is then amplified to actuate the output alarm signal. A delay of approximately two seconds is built into the circuit to discriminate against short lived transients and thereby eliminate false warnings and clearings due to such causes. The control unit contains a test circuit to power the test lamp in the sensor at a frequency of 10 cps when the test switch is actuated, resulting in a truly functional test of the system.

Results and Discussion - The Fenwal Surveillance Fire Detector system, SFD-500, was evaluated in the laboratory to determine its basic characteristics of operation and dependability. The system consisted of one control unit P/N 10-100041-001 and four sensors P/N 10-200000-005. These were assembled with a selector switch, test switch and warning lamps in accordance with the manufacturers instructions.

In order to determine whether the sensitivity of the system is affected by the number of sensors viewing a fire, the maximum distance at which detection would occur, was determined with four sensors viewing a stable source of radiation and with one sensor viewing the source. Since the FAA TSO-C79 requires the use of 40 watt colored incandescent lamps in its Qualification Performance Requirements, and because the lamps provide a more consistent and stable source than the 5-inch pan fire, they were used in making the comparison. The 5-inch pan fire was used only as a verification that the system performs satisfactorily on hydrocarbon flames. The results of this comparison are summarized in Table VII. These tests were conducted with a background radiation of approximately one foot-candle.

TABLE VII

SENSITIVITY TEST RESULT SUMMARY ON
THE FENWAL SFD-500 SURVEILLANCE FIRE DETECTION SYSTEM

	Maximum Detection Distance in Feet			
	40-watt Incandescent Lamp			
Viewed by	Red	Yellow	Orange	5-inch dia. Pan Gasoline Fire
	(ft.)	(ft.)	(ft.)	(ft.)
4 sensors	5	4½	5½	8 or more
1 sensor	2	2	2	

Because the Fenwal system operates on the flicker principle, mechanical flicking of approximately 15 cycles-per-second was provided when the incandescent lamps were used as a radiation source. The effect of sunlight on the system operation was determined by subjecting the four sensors to bright midafternoon sunlight on a clear day in April. With the sensors facing the sunlight, the system false alarmed almost continuously. On occasion when the alarm did clear on its own accord, a slight movement of anything within the cone of vision would bring on the alarm again. With the sensors facing away from the sun, a false warning usually resulted from movements within the cone of vision. The 5-inch pan gasoline fire was detected at a distance of 4 feet which is one of the requirements of TSO-C79.

The time required for detection was not mentioned in these test results. As mentioned in the principle of operation, a delay to provide time or discrimination is designed into this system, therefore, response and clearing require approximately 2 seconds and, if at the end of this period no detection results, there will be no detection provided the radiation source is constant.

To determine the effect on system operation of moisture and saline solutions, in the connectors, a set of leads was branched off from the wires connecting the sensors to the control unit. The ends of these leads were immersed in demineralized water and in a 20-percent salt water solution. The incandescent lamp tests were repeated under each of these conditions. No deviation from the results given in Table VII was noted.

Pyrotector Optical Fire Detection System:

System Description - The Pyrotector Optical Fire Detection system consisted of a control amplifier P/N 30-303A, and four flame detectors P/N 30-215. These were properly connected to a 28 volt d-c power source, a test switch, and a fire warning lamp.

The flame detector or sensor consists of a hermetically sealed dome assembly that houses a solid state photoconductive cell structure. The dome and cell assembly is potted into a stainless steel housing which incorporates a mounting flange and the required wires for connecting into the system.

The control amplifier is a unit fitted with electrical connectors and contains a diode mixing network, a transistor relay control circuit, alarm relay, and a blocking diode to prevent negative voltage damage.

Principle of Operation - The photoconductive cell structure in the sensor consists essentially of two photoresistive semiconductors, one sensitive to blue radiation and the other sensitive to red radiation. When this cell structure is subjected to radiation from a flame, the increased ratio of red to blue results in an unbalance in the circuit that provides a signal voltage to the control amplifier sufficient to effect the operation of the alarm relay. The time interval required to provide the fire warning is in the order of milliseconds. Upon the cessation of flame, the cell structure returns the circuit to its proper balance and the system resets in milliseconds for continued surveillance.

Results and Discussion - The Pyrotector Optical Fire Detection system evaluated consisted of one control amplifier P/N 30-303A, and four flame detectors P/N 30-215, properly connected to a test switch and a warning lamp and powered by a 28 volt d-c supply.

The sensitivity of this system was determined when exposed to radiation from various sources. Table VIII is a summary of the results, conducted with a background radiation of approximately one-foot candle.

TABLE VIII

SENSITIVITY TEST RESULT SUMMARY
ON THE PYROTECTOR OPTICAL FIRE DETECTION SYSTEM

Maximum Detection Distance in Feet

Viewed by	40-Watt Incandescent Lamp Red	Yellow	Orange	5-inch dia. Pan Gasoline Fire
	(ft.)	(ft.)	(ft.)	(ft.)
4 sensors	3	3	3	4
1 sensor	3	3	3	

The effect of sunlight on the operation of the system was determined by subjecting the four sensors to bright sunlight. No false warning resulted when the sensors were subject to sunlight, whether facing toward or away from the direct sunlight. However, the system did not respond to the test switch nor did it sense the presence of the 5-inch pan gasoline fire.

To determine the effect on system operation of moisture and saline solution, a set of leads was branched off from the wires connecting the sensors to the control unit. The ends of these leads were immersed in demineralized water and in a 20-percent salt water solution. The incandescent lamp tests were repeated under each of these two conditions. No diviation from the results given in Table VIII was noted.

Graviner Surveillance Fire Detection System:

System Description and Operation - The Graviner Surveillance Fire Detector system examined in the laboratory consisted of four sensors Model DS-591, and one control unit Model DSK 6069. This control unit included the test switch and the warning indicator.

The sensing head for this system consists essentially of a photocell which is sensitive to ultra-violet light in the 0.21 to 0.26 micron range only. It is completely insensitive to the visual and infrared bands. The photocell is mounted in the sensing head so that its included viewing angle is 180°. Covering the photocell is a removable quartz dome specially treated to prevent attenuation of U.V. transmission by hydrocarbon. A wire guard is fitted over the quartz dome to prevent mechanical damage during servicing. An ultra-violet test lamp is built into the sensing head external to the quartz dome for testing the integrity of the entire system.

The control unit is an arrangement containing electronic circuitry, a test switch, a warning lamp, and connectors for the four sensing heads and for the power sources. This circuitry monitors the condition of each sensing head and effects a warning when the photocell receives the required amount of ultra-violet radiation, and conversely, clears the signal when the radiation has subsided.

Results and Discussion - The Graviner Surveillance Fire Detector system as described above was evaluated for dependability and operating characteristics in the laboratory. The system responded to the test switch in 1 to 2 seconds and cleared the signal upon releasing the test switch in approximately 5 seconds. The system was completely blind to the 40-watt colored incandescent lamps. No alarm resulted even when the lamp was brought in contact with a sensor. The response of the system to the 5-inch gasoline pan fire was determined first in subdued light of approximately 1-foot candle. At a distance of 3 feet, with four sensors viewing the fire, an alarm was signaled in 3 seconds. With only one sensor viewing the fire the response was in 26 seconds. The response of the system was then determined with the sensors looking into bright sunlight (at 2:00 p.m. on a clear September day). No false warning resulted from the direct exposure of sunlight. Under these lighting conditions the response to the 5-inch pan fire at 3 feet was 3 seconds, the same as when evaluated in subdued light. This indicates that the system is unaffected by background radiation ranging from fairly dark to bright sunlight.

Firetec Overheat and Fire Detection System:

System Description and Operation - The Firetec Overheat and Fire Detection system examined in the laboratory consisted of nine detectors and one control unit. Each detector of this system contains two thermocouples connected in opposition. One thermocouple is exposed directly to any heat source, the other is shrouded in high alumina ceramic. The output of each detector is the result of the outputs of the exposed and shielded thermocouples and is directly related to the temperature difference. An average system generally consists of up to 20 of these detector units connected in series. The output of a system is the sum of the output of the individual detectors.

The output of the detector chain is fed, by ordinary cable or conductors, to the solid state control unit. This control unit comprises an Oscillator Chopper/Amplifier d-c level Detector and very comprehensive test circuits. The control unit is of encapsulated modular construction and the operate and reset values are continuously adjustable over a wide range to meet any installation requirements.

The impedance of the detector is approximately 30 milliohms. This, and the fact that the detector chain is isolated from the power supply provides a system that will not false alarm and will continue to function properly when the sensing circuit is shorted to ground, not only in one place but in more than one location, since shorts to ground of this nature generally have a resistance much greater than 30 milliohms.

Results and Discussion - This system is basically a rate of rise detection system. Therefore, instead of using the set point as a means for determining the effect of malfunctions on system operation, the response time, when subjected to the 2000°F flame, was used for this purpose.

The response time of the system when one out of sensors was subjected to the standard flame was 1 second. The clearing time after removal from a 1-minute exposure also was 1 second. This same sensor was shorted to ground on each side, that is, both leads to the sensor were grounded. This was accomplished using clip leads which provided a ground as good or better than would occur from an accidental grounding. The test switch was then actuated and the warning lamp failed to light indicating an inoperative system, or at least a system with a fault. The sensor was then subjected to the standard flame and an alarm occurred in 3 seconds, thus indicating that the system is insensitive to shorts or partial isolation by shorts other than extremely low resistance shorts.